UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC STUDIES OF A PRESSURE REDUCING SYSTEM FOR THE TRANSFORMER COOLING WATER--GRAND COULEE POWER PLANT
COLUMBIA BASIN PROJECT, WASHINGTON

Hydraulic Laboratory Report No. Hyd-308

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

March 30, 1951

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Laboratory Report No. Hyd-308
Hydraulic Laboratory
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Subject: Hydraulic studies of a pressure reducing system for the transformer cooling water--Grand Coulee Power Plant--Columbia Basin Project, Washington

PURPOSE OF STUDY

To develop a satisfactory system, using a plug valve and two thin plate orifices in a 3-inch pipe line, for reducing the pressure of the water before it enters the transformer cooling system; and thus replace the present pressure-regulating valves which "hunt" and require excessive adjustment and maintenance.

CONCLUSIONS

1. The plug valve-orifice system in which two 2.086-inch-diameter, square-edge, thin-plate orifices placed downstream of a plug valve in a 3-inch pipe line (Figure 2A) will operate satisfactorily over a discharge range of 0.225 to 1.34 cfs for any upstream pressure when the differential head across the system is 115 feet and the downstream pressure is not less than 18 feet of water.

2. With an upstream pressure of 153 feet and a variable head differential across the system as shown on Figures 4A and B, there is local cavitation at discharges exceeding 0.75 cfs. The downstream or back pressure is too low for the 153-foot upstream pressure. The minimum back pressure needed to eliminate cavitation with this upstream pressure was not determined in the test program.

3. The orifice spacing used in the tests did not affect the loss through individual orifices. The loss through each was the same as for an unobstructed single orifice in a line (Figure 5); thus, for a given back pressure the plug valve must absorb changes in loss due to variations in upstream pressure when a constant supply of cooling water is desired.

4. Operation of the system with the plug valve placed downstream of the orifices as shown on Figure 2B, is unsatisfactory. Pressures at the valve inlet are low for the upper discharge range and further reduction in pressure as the water passes through the valve causes cavitation below the valve. The pressure curves shown on Figure 4D for piezometers 7 and 8, although not indicating cavitation pressures at these points, are very low. The cavitation evidenced in the tests was no doubt of a local nature and in the vicinity of the low-pressure zone.

5. Regardless of whether the plug valve is upstream or downstream of the orifices, the greater portion of the head loss across the plug valve-orifice system occurs at the valve for the smaller discharges and at the orifices for the larger discharges.

6. The admission of air into the subatmospheric pressure regions will eliminate cavitation in either arrangement. However, too much air causes pipe line vibration, which for some undetermined reason is more severe in the system in which the valve is placed downstream of the orifices.

7. Effective pressure reduction can be obtained for any head and discharge by a plug valve-orifice system, but the arrangement, spacing, number, and size of orifices are factors which must be given careful consideration. In cases of constant discharge under constant head and a constant head reduction, effective pressure reducing systems can be made by using successive orifices alone in a pipe line.

8. Although the losses for plug valves will differ with different makes they should not vary widely for the same standard and should compare closely with those obtained in these tests.

RECOMMENDATIONS

1. Use the plug valve-orifice system, in which the valve is placed upstream of the orifices as shown on Figure 2A, to reduce the pressure of the transformer cooling water at Grand Coulee Dam.

2. The minimum spacing of the valve and orifices in the system should be as shown on the figure.

3. Regulate the back pressure but not to exceed the safe working pressure of the system rather than admit air to eliminate cavitation should any be encountered during normal operation.

INTRODUCTION

Cooling water for the transformers at Grand Coulee Dam is supplied through a pipe system originating at the turbine scroll case. Three-inch pressure-regulating valves have been used in these lines to reduce the pressure to about 60 feet of water in the transformer cooling tubes. The first valves installed were equipped with pilot controls. Detail C (Figure 6) is typical. The pilot valves were too sensitive to line pressure fluctuations, producing "hunting" or continual movement of the operating mechanism of the pressure-regulating valves, causing excessive wear and maintenance. In subsequent installations the pilot valves were eliminated; Detail C (Figure 7) is typical. The "hunting" was reduced but not eliminated so that excessive wear still occurred. A total of 31 pressure-regulating valves were provided, including 15 emergency alternates.

The Hydraulic Machinery Division proposed using a plug valve for regulation in conjunction with two thin-plate orifices to reduce the pressure, simplify the system, and decrease maintenance. A test program was initiated to study the two proposed pressure-reducing systems shown on Figure 2. The program was planned to include the following parts:

a. With the orifices placed downstream from the plug valve, study the head losses at a constant upstream pressure head of 185 feet of water, with a 115-foot constant head loss across the system, and for a discharge range of 0.225 to 1.340 cubic feet per second.

b. The same arrangement as (a) except with variable head loss across the system, and the back pressure as near atmospheric as possible.

c. The same as (b) except admit air to the subatmospheric pressure area behind the downstream orifice.

d. The same conditions as (b) and (c) except with the plug valve installed downstream from the orifices.

THE INVESTIGATION

Description of the Pressure Reducer Test Apparatus

The test apparatus consisted of a 3-inch plug valve and two square-edge, thin-plate, 2.086-inch-diameter orifices contained in a 3-inch pipe line placed in the laboratory supply system. The two arrangements of valve and orifices tested are shown on Figures 1 and 2.

The orifices were machined from 1/8-inch brass plate and inserted between the flanges of sections of 3-inch pipe. The plug valve was a 75-pound water or gas, cast aluminum valve manufactured by Nordstrum, used previously in the laboratory. Pressure taps, or piezometers, were placed at specific locations along the horizontal centerline of the pipe as shown on Figure 2. The upstream pressure on the pressure reducing apparatus was controlled by gate valves in the laboratory supply system while the back pressure or downstream pressure was controlled by a gate valve in the downstream piping which emptied into the laboratory storage channel. The water was supplied by two 12-inch centrifugal pumps operating in series and measured by an orifice venturi meter in the laboratory supply system.

A commercial gas meter was used to measure air admitted to low-pressure regions to eliminate cavitation. This meter was used after the quantity of air was found to be too small to permit a satisfactory measurement by an orifice. However, the only meter available was too large for accurate measurement of the small quantity and the quantities recorded were therefore only approximate.

Plug Valve Located Upstream from the Two Orifices

The maximum pressure head from the two pumps was 153 feet of water for the maximum specified discharge of 1.34 cfs through the system. This 153-foot head was the basic inlet head used in the tests, which was 32 feet less than the 185 feet specified. A back pressure of 38 feet was maintained during the first test to give the specified constant head loss of 115 feet across the system. The losses for the various components of the system are shown on Figure 3A and the pressures on Figure 3B. It is evident from Figure 3A that most of the loss occurs in the plug valve at small discharges and in the orifices at high discharges. For example, with 0.225 cfs discharge, the total loss for the orifices is 4 feet and the plug valve 111 feet; whereas, for a discharge of 1.34 cfs the loss for the orifices is 108 feet, and the plug valve 7 feet, or a total of 115 feet of water in both cases. The pressure distribution curves on Figure 3B show the pressures at several points along the system. The location of the piezometers is shown on Figure 2A.

Figure 5 illustrates another method of showing the losses. On Figure 5 the pressures at the piezometers are plotted in comparison with theoretical curves for single orifices calculated from the information given in Figure 12, Part 1, page 34, of the 1924 ASME report "Fluid Meters." Only three typical curves are shown, because with this method a separate curve is required for each discharge.

The system operated satisfactorily during this test with no evidence of cavitation, although moderate vibration occurred at discharges of 1 cfs and greater. This vibration appeared to be the result of the dissipation of the energy of the high-velocity jet of water in the pipe downstream from the orifices.

The back pressure was reduced until cavitation started to occur at the maximum discharge with a differential of 115 feet of water. This was done to determine the minimum back pressure for the system to function properly with the 115-foot differential. This minimum safe back pressure was determined to be 18 feet of water for a discharge of 1.34 cfs, which reduced the inlet head from 153 to 134 feet of water. Head losses and pressures are shown on Figures 3C and D. The losses for the valve and orifices were the same as in the preceding test, and the pressures were displaced by the difference of the inlet heads. The pressure at piezometer P6 (one-half pipe diameter downstream of the downstream orifice) with a discharge of 1.34 cfs was a minus 25 feet, which approached the vapor pressure of water. A reduction in pressure upstream from the first orifice combined with a reduced discharge will permit even a lower back pressure. No attempt was made to determine the minimum back pressure for each of the test discharges for the constant specified loss of 115 feet. Satisfactory pressure conditions will exist in this pressure reducing system for the specified head and head differential because the pressure below the downstream orifice will rise as the back pressure is increased.

There are innumerable combinations of discharge, inlet pressures, and back pressures that are safe, but for practical regulation, if the system is operated at inlet and back pressures that are safe for maximum discharge, then no trouble will occur at lesser discharges. There is an exception, however; at small discharges most of the loss is taken in the valve. For these small discharges there can be a critical head on the valve depending on degree of valve openings at which cavitation will occur in the valve. This condition is not expected for the system at Grand Coulee unless there is continual operation at high head and at discharges appreciably below the maximum, 1.34 cfs. If such is the case, smaller orifices can be used to alleviate the high loss through the valve. An interesting observation was made during the tests. Cavitation could not be made to occur in the plug valve or immediately downstream with the available head, at very small openings, because of the high head losses in sudden contractions and enlargements in the valve flow passage. The water enters the valve through a sudden contraction at the plug, passes into a sudden enlargement inside the plug, leaves the plug through a sudden contraction, and enters a sudden enlargement into the pipe. This permits a very large head loss without obtaining cavitation pressure.

The results of a test with an inlet head of 153 feet of water and the back pressure as near atmospheric as possible are shown in Figures 4A and B. At all discharges less than 0.78 cfs, back pressure was applied to keep the downstream piezometer openings under water. This back pressure was maintained at a minimum of about 2 feet of water. The loss through the orifices was the same as in the previous tests as shown on Figures 3A and C, with the plug valve absorbing any change in inlet head. Cavitation was present downstream of the second orifice at discharges from 0.78 to 1.34 cfs, although the pressure at piezometer P6 did not measure vapor pressure (Figure 4B); this indicated that the cavitation occurred locally and the piezometer was not located correctly to measure it. However, at the maximum discharge the pressure at piezometer P6 does approach vapor pressure. Operation under these conditions was unsatisfactory for discharges in excess of 0.78 cfs.

Sufficient air to just eliminate cavitation was supplied immediately downstream from the second orifice. The amount was too small to be accurately measured with available equipment, but was approximately 1 to 2 cubic feet of free air per minute. An excess of air created a severe vibration in the pipe line.

Plug Valve Located Downstream from the Two Orifices

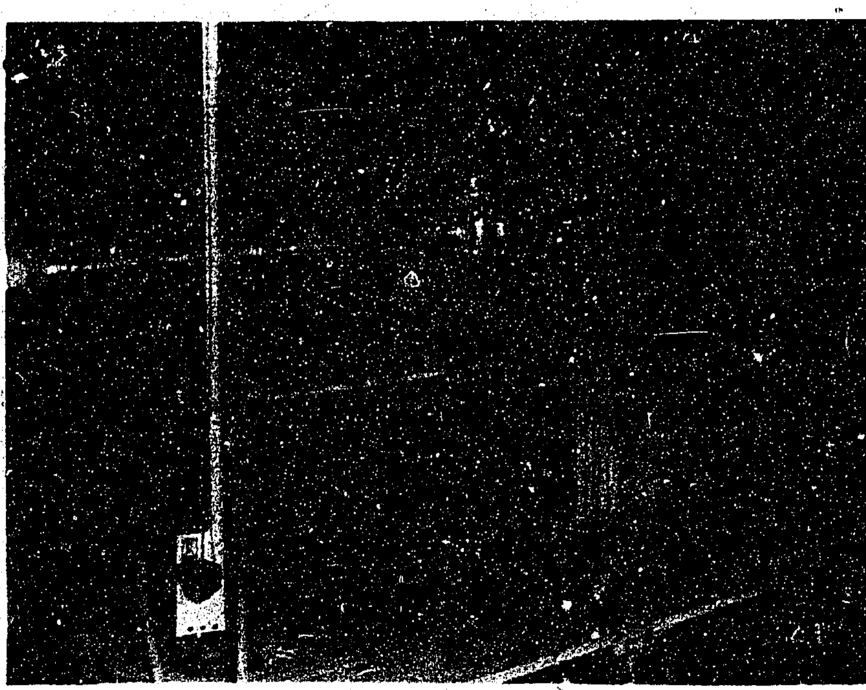
An installation sketch of the plug valve located downstream from the two orifices is shown in Figure 2B. The inlet head P1 was set at 153 feet of water and the back pressure was maintained at atmospheric for discharges less than 0.80 cfs to keep the downstream piezometers under water. The loss-in-head curves (Figure 4C) are similar to the loss when the plug valve is placed upstream of the orifices. Cavitation, now occurring at the valve, is much more severe and is present in the range of 0.50 to 1.34 cfs (Figure 4D). This cavitation is local in the plug valve because of the lower pressure gradient through the valve. Air admission relieves the cavitation but the system vibrates severely.

Piezometer Locations

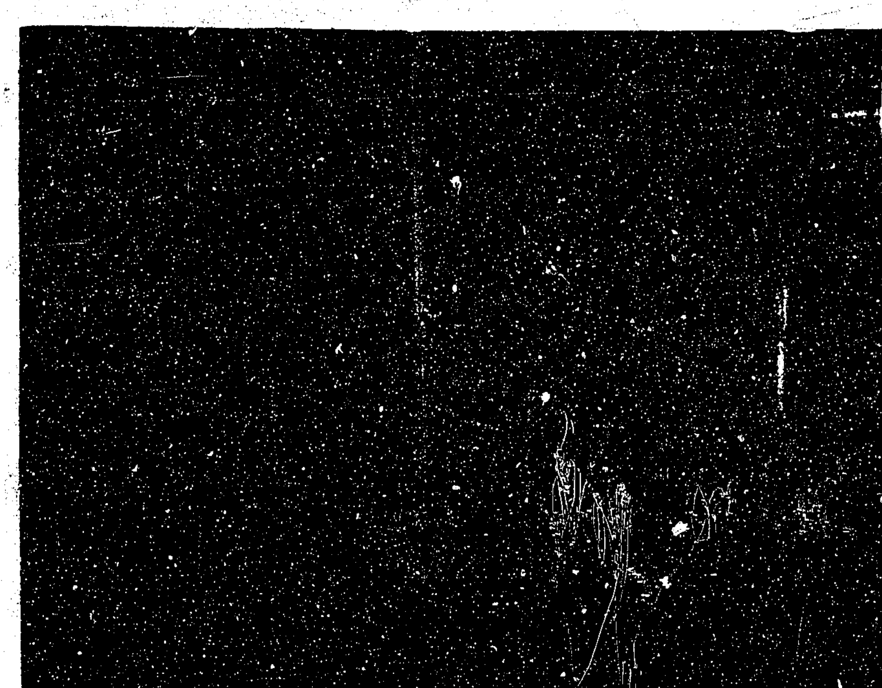
The piezometer locations shown on Figures 2A and B were selected where the minimum pressures and full recovery pressures were expected to occur. These locations were satisfactory until cavitation developed. Two conditions of cavitation were encountered; local cavitation which extends but a very short lineal distance below the obstruction causing vapor pressure, and general cavitation where the cavitation envelope surrounds the jet and extends downstream. With local cavitation the vapor pressure occurs and recovers to a pressure greater than vapor pressure before reaching the piezometer location selected for the minimum pressure; thus, the piezometer does not record the minimum pressure. In cases of general cavitation the envelope extends downstream a sufficient distance to affect the pressure at the piezometer location selected for full recovery pressure, thus recording low, erroneous recovery pressures.

Installation Characteristics

The data contained in this report are valid only for an installation such as shown on Figure 2. It should be realized that the losses in this study are for the particular plug valve, orifices, and piezometric locations shown in Figure 2, and changes in the size or location of the orifices, or the type and location of regulating valve can appreciably affect the losses.

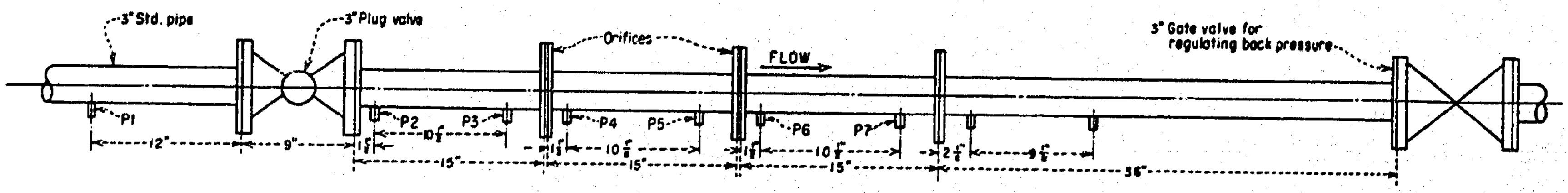


A. Plug Valve Installed Upstream From Orifices

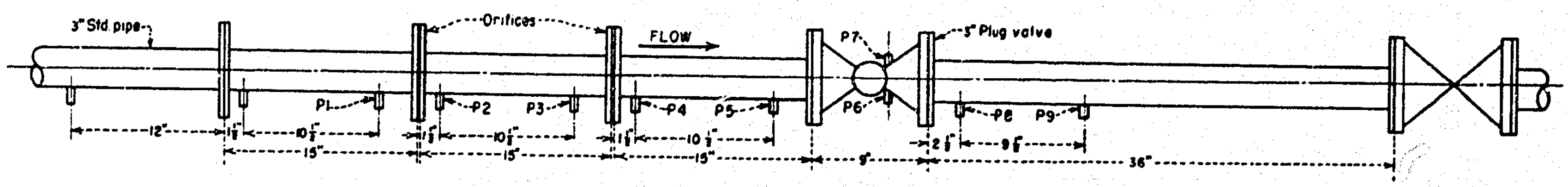


B. Plug Valve Installed Downstream From Orifices

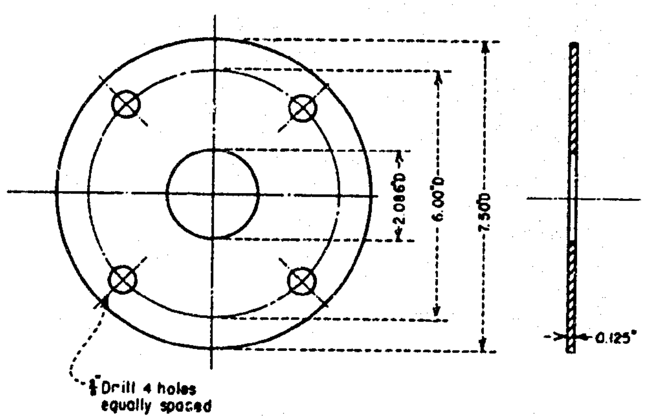
Columbia Basin Project--Washington
Transformer Cooling Water
Pressure Reducer Test Installations



A. PLAN WITH ORIFICES DOWNSTREAM FROM PLUG VALVE



B. PLAN WITH ORIFICES UPSTREAM FROM PLUG VALVE



C. ORIFICE PLATE DETAIL

NOTE

P1, P2, etc. is abbreviation for piezometer No. 1, piezometer No. 2, etc.

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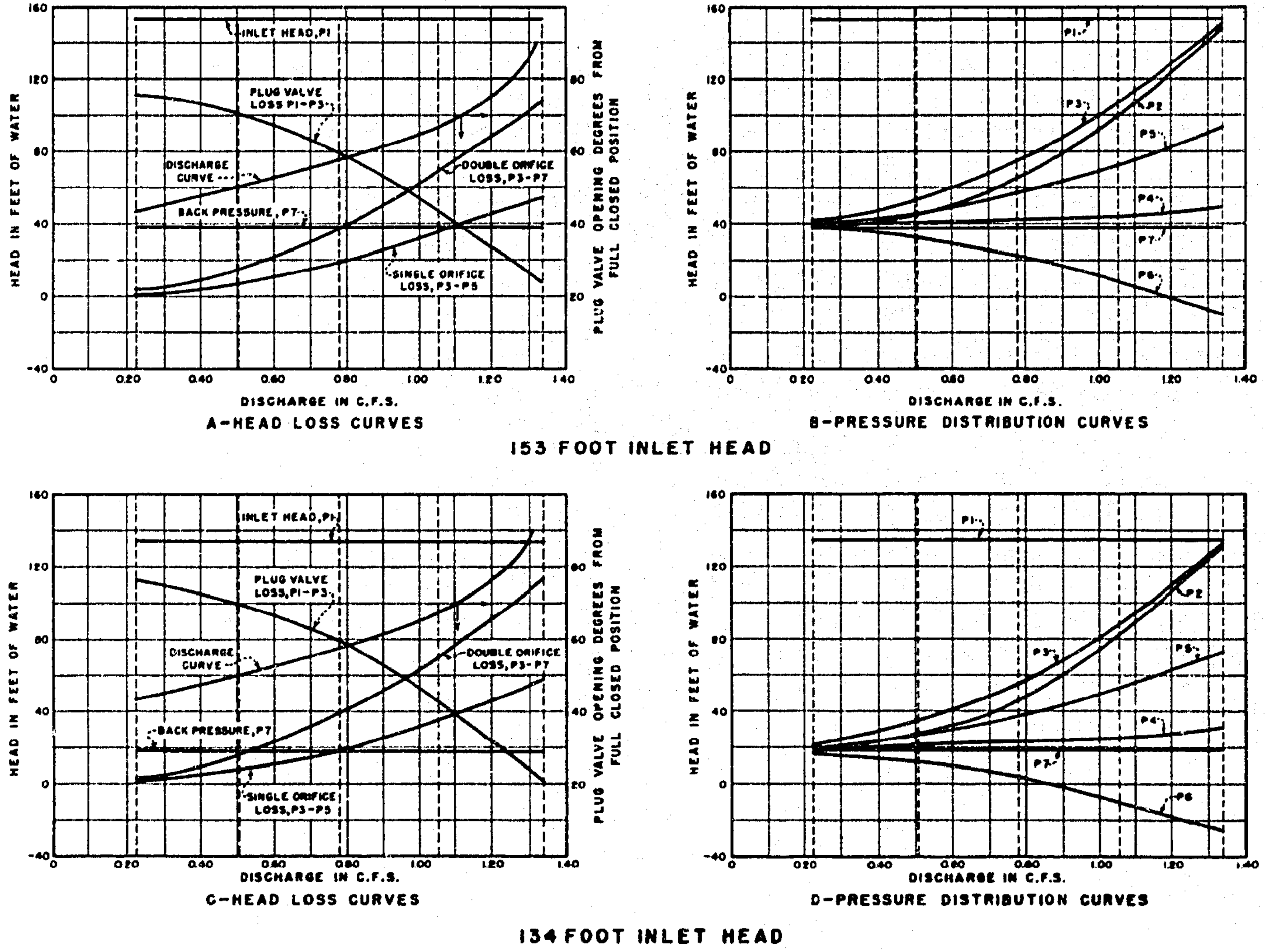
TRANSFORMER COOLING WATER
PROPOSED PRESSURE REDUCER SYSTEMS

FIGURE 2
REPORT HYD. 306



NOTES

1. All curves apply to plug valve upstream from the orifices.
2. P1, P2, etc. indicate piezometer numbers, see figure 2.
3. Vertical dotted lines represent test discharges.

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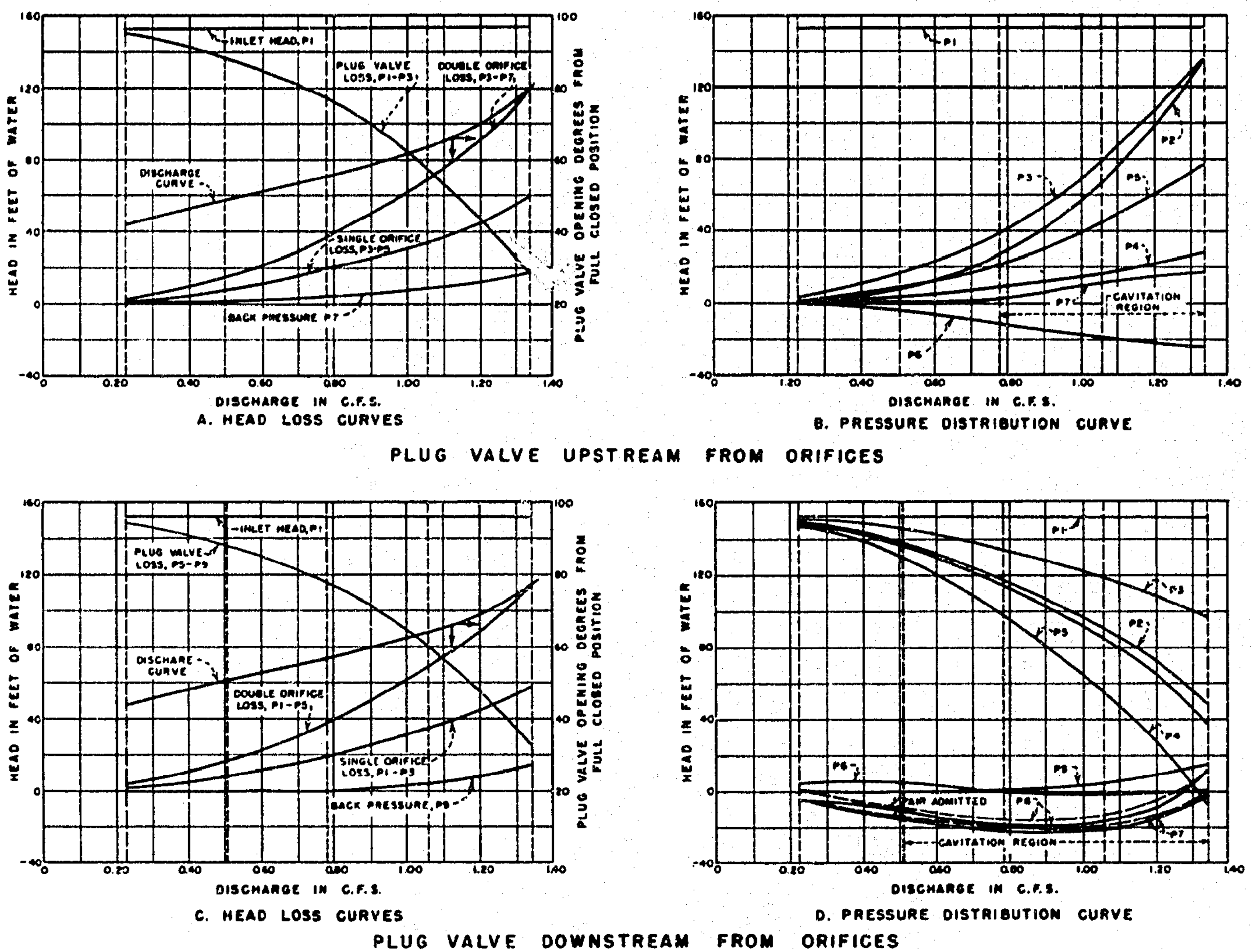
GRAND COULEE POWER PLANT
TRANSFORMER COOLING WATER
PRESSURE REDUCER

HEAD LOSS AND PRESSURE DISTRIBUTION CURVES
CONSTANT DIFFERENTIAL ACROSS SYSTEM

FIGURE 3.
REPORT HYD. 308



NOTES

1. All curves apply to 153 foot inlet head.
2. P1, P2, etc. indicate piezometer numbers, see figure 2.
3. Vertical dotted lines represent test discharges.

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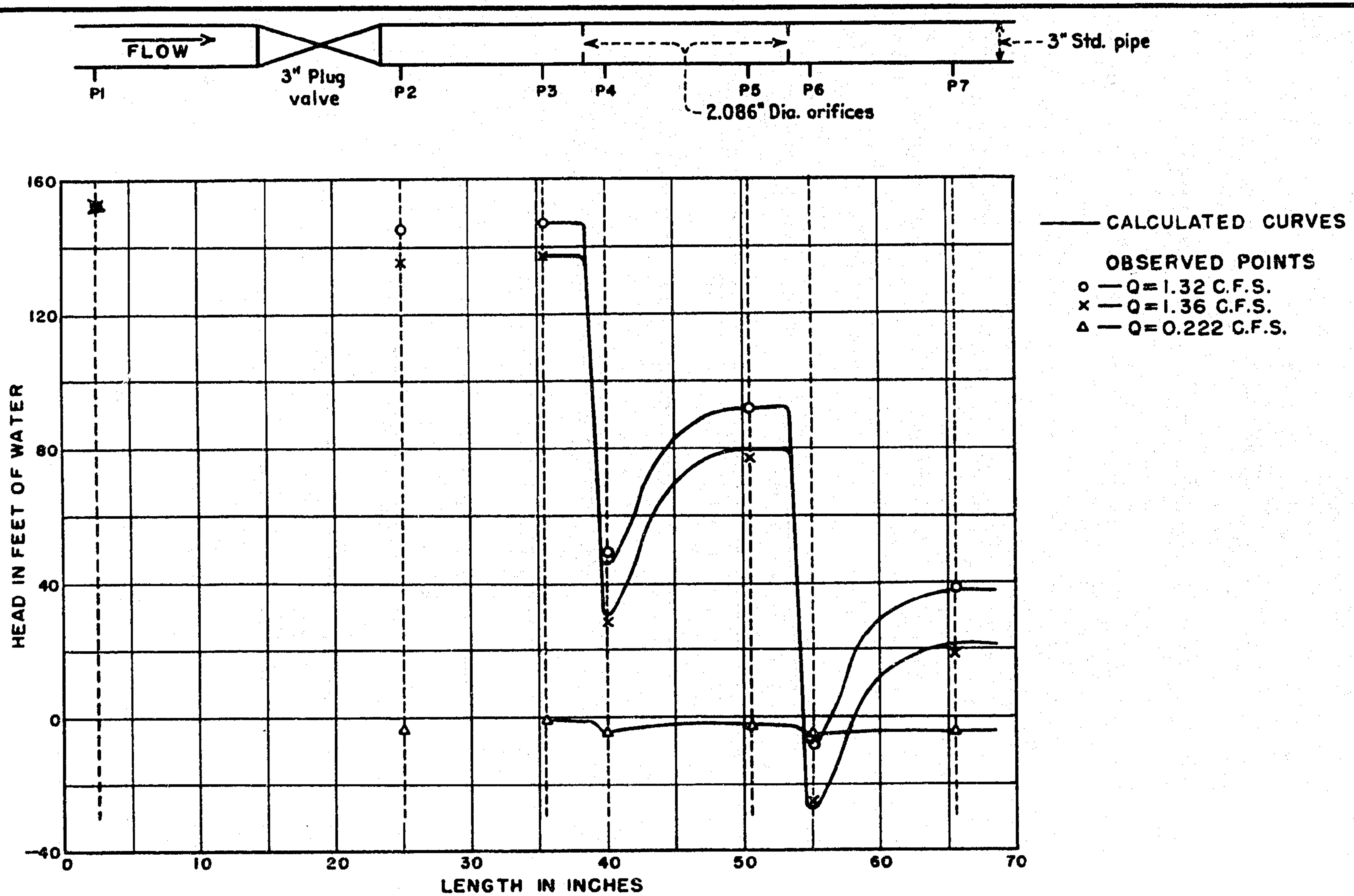
GRAND COULEE POWER PLANT

TRANSFORMER COOLING WATER PRESSURE REDUCER

HEAD LOSS AND PRESSURE DISTRIBUTION CURVES VARIABLE DIFFERENTIAL ACROSS SYSTEM

FIGURE 4
REPORT HYD. 308



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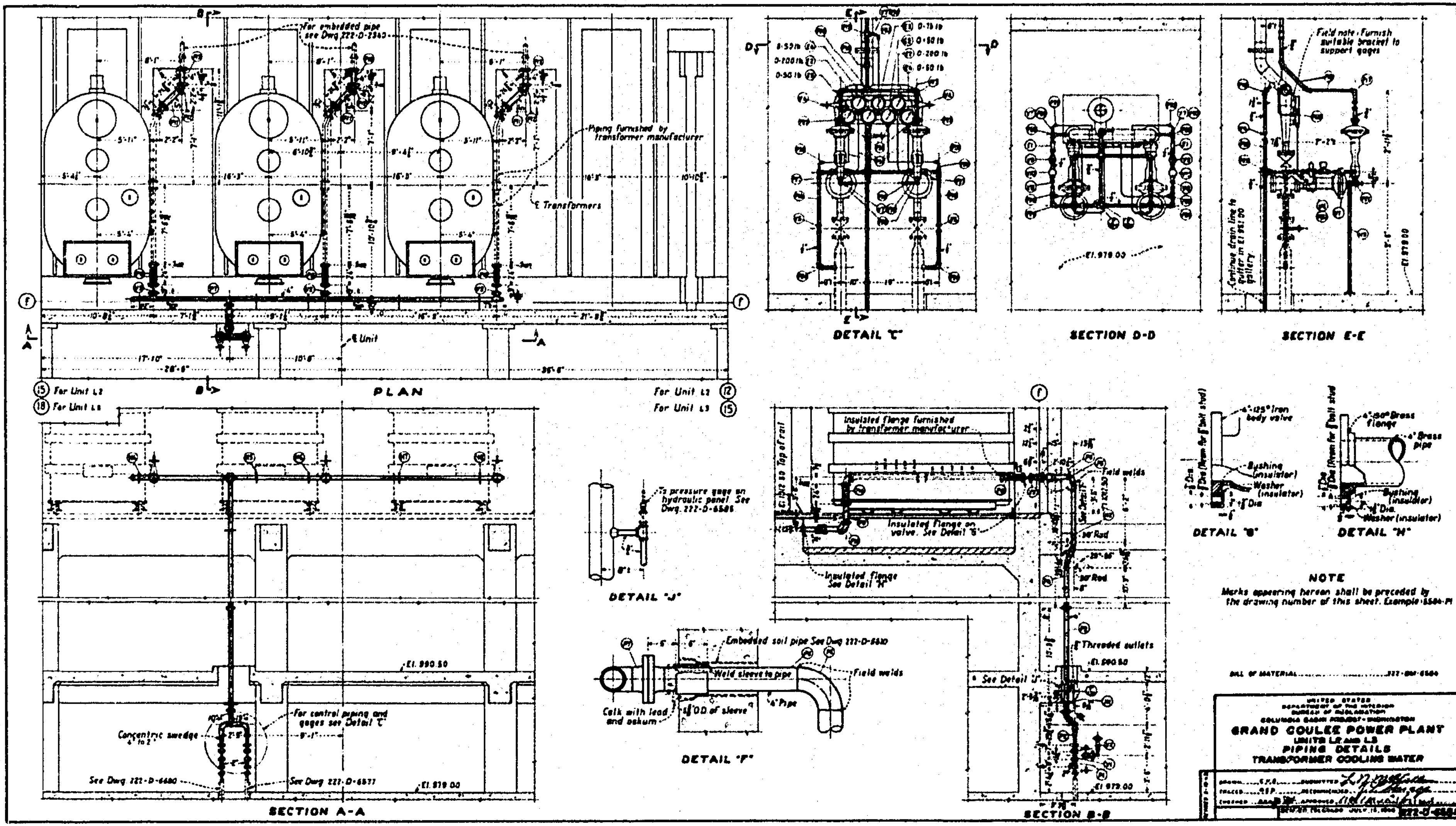
GRAND COULEE POWER PLANT
TRANSFORMER COOLING WATER
PRESSURE REDUCER HEAD LOSS CURVES

FIGURE 5
REPORT HYD. 308


PLAN
SECTION A-A
DETAIL "C"
SECTION D-D
SECTION E-E
DETAIL "J"
DETAIL "F"
SECTION B-B
DETAIL "G"
DETAIL "H"
For embedded pipe see Dwg 222-D-2340
Piping furnished by transformer manufacturer
℄ Transformers
℄ Unit
For Unit L2
For Unit L3
For control piping and gages see Detail "C"
Concentric swedge 4" to 2"
See Dwg 222-D-6480
See Dwg 222-D-6577
El. 990.50
El. 979.00
To pressure gage on hydraulic panel. See Dwg. 222-D-6585
Embedded soil pipe See Dwg 222-D-6510
Weld sleeve to pipe
Field welds
Calk with lead and oakum
4" Pipe
Insulated flange furnished by transformer manufacturer
Insulated flange on valve. See Detail "G"
Insulated flange See Detail "H"
Threaded outlets
See Detail "J"
Field note: Furnish suitable bracket to support gages
Continue drain line to gutter in El 951.20 gallery
4" 125# Iron body valve
4" 150# Brass flange
4" Brass pipe
Bushing (insulator)
Washer (insulator)
NOTE
Marks appearing hereon shall be preceded by the drawing number of this sheet. Example: 6584-P1
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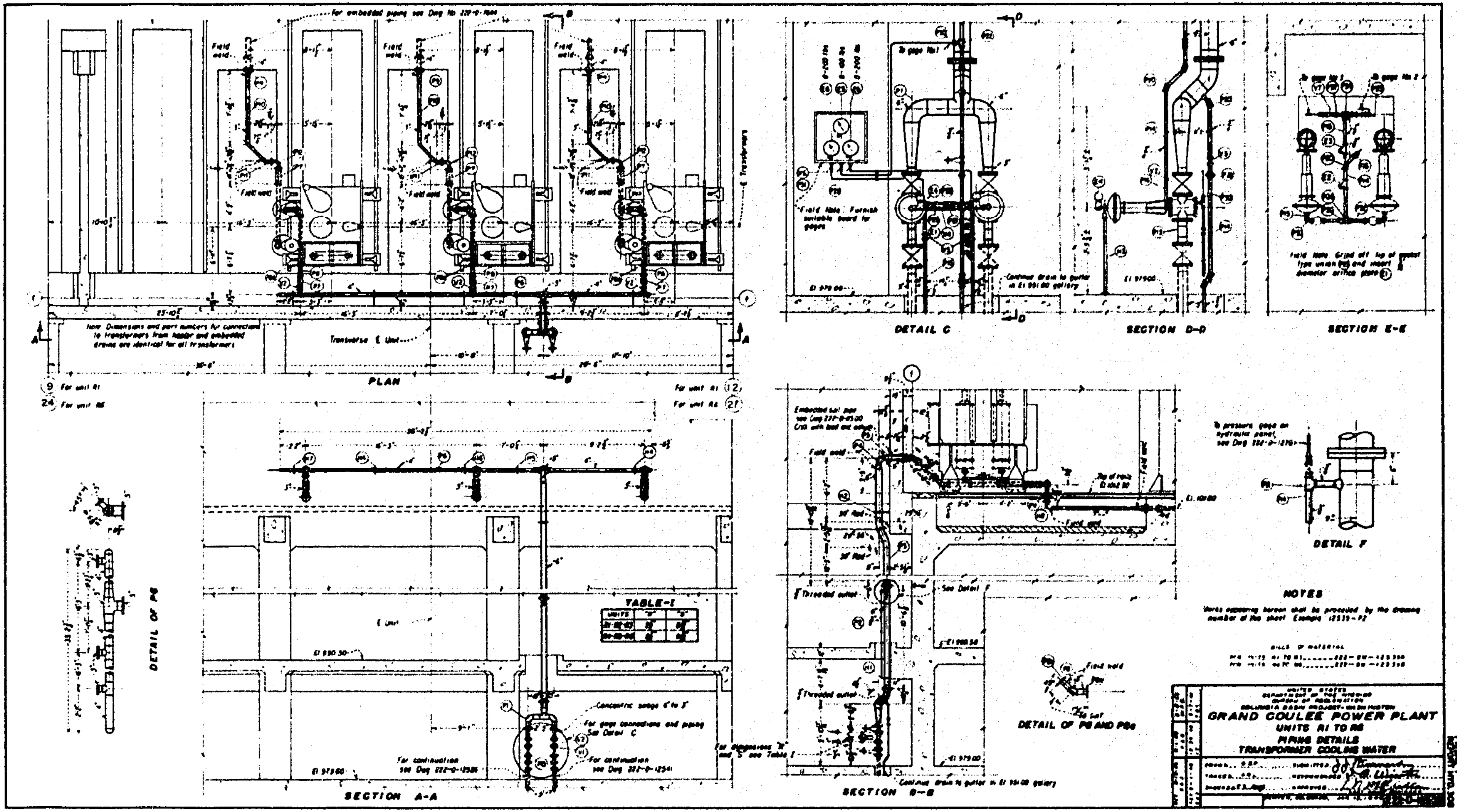
GRAND COULEE POWER PLANT
UNITS L2 AND L3
PIPING DETAILS
TRANSFORMER COOLING WATER


PLAN
SECTION A-A
DETAIL C
SECTION D-D
SECTION E-E
SECTION B-B
DETAIL F
DETAIL OF P8
DETAIL OF P8 AND P8a
TABLE-I
NOTES
GRAND COULEE POWER PLANT
UNITS R1 TO R6
PIPING DETAILS
TRANSFORMER COOLING WATER